Divisional Commissioner’s Office Complex

A Summary of the Seismic Evaluation and Retrofit Process

Delhi Earthquake Safety Initiative for Lifeline Buildings

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Executive Summary

The Divisional Commissioner’s Office Complex, located at 5 Sham Nath Marg, houses the offices of Delhi Government officials with responsibility for disaster management. In addition to the Divisional Commissioner, the Delhi Disaster Management Authority (DDMA), the Labour Commissioner, and a police control room (dispatch center) also reside in the four buildings on the site. Block A is a single storey unreinforced brick bearing wall building that is ninety years old, and may qualify for heritage status. Block B is a ground plus two storey unreinforced brick bearing wall building, which was constructed much more recently. Block C is a ground plus three storey reinforced concrete frame building, with masonry bearing walls in the ground story, a building type called the Bombay Pattern. Block D is a ground plus three storey reinforced concrete frame building with brick infill walls.

Delhi Public Works Department (PWD) began the assessment and retrofit decision-making process by gathering information about the site and buildings. No drawings were available for any of the buildings, so Delhi PWD had measured drawings made, conducted geotechnical investigations, performed non-destructive tests to determine existing material strengths and conditions, and screened the buildings for seismic deficiencies. Blocks A and B were assessed using the Indian Standard for the seismic retrofit of unreinforced masonry buildings, IS 13935. Blocks C and D were assessed using the American Society of Civil Engineers (ASCE) standard for existing buildings, ASCE 31-03. Delhi PWD determined that liquefaction was unlikely to occur at the site.

The performance criteria for all four blocks were set at Life Safety plus Damage Control for the Design Basis Earthquake (DBE), which had a peak ground acceleration of 0.12 g, and at Collapse Prevention for the Maximum Considered Earthquake (MCE), which had a peak ground acceleration of 0.24 g. All four buildings had seismic deficiencies and required retrofitting to achieve the desired performance. Delhi government decided to retrofit Blocks C and D with reinforced concrete shear walls and, as of this writing, had not reached a decision on whether to retrofit or replace Blocks A and B. If the Delhi government decides to retrofit Block A, then architectural and historic preservation issues will need to be addressed, in addition to disruption issues. The Block C and D retrofits were conservatively designed and should result in limited structural damage, repairable in a matter of months, even in the MCE. Block D is likely to achieve Immediate Occupancy performance in the DBE, meaning that users can get back into the buildings after minor cleanup.

A lack of surge space caused the Delhi PWD to retrofit Block D with its occupants in place. Making necessary accommodations for the occupants and working to minimize disruption caused construction to progress more slowly than originally planned. Disruption has not been managed as successfully as at Ludlow Castle School. The retrofit contractor also had to deal with a highly constrained site, the continued operation of the police control room in the basement, and an underground tank that impeded foundation excavations. All of these items contributed to project delays, and at the time this report was written, construction had not been completed. Delhi PWD provided construction quality control using their standard procedures. The total retrofit cost for Block D was 49 lakh rupees, approximately 25% of the estimated replacement cost. At the time of this report, Block C’s retrofit design was awaiting sanction by the Labour Department. The estimated cost for Block C is 65 lakh rupees, approximately 38% of the estimated replacement cost. With the experience of the Block D retrofit, Delhi PWD can make adjustments to make construction go more smoothly for Block C. Delhi government officials gained valuable experience through the process of making decisions and managing a multi-building seismic improvement project at their own offices.
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Introduction

The Divisional Commissioner’s Office complex consists of four small office buildings located at 5 Sham Nath Marg. The main project participants from the Delhi government, who have responsibility for disaster management, have their offices in these buildings. Block A contains the Divisional Commissioner’s office and the offices of the Additional District Magistrate, who is the project head at DDMA. The offices in Block B include the remainder of DDMA, the Finance Commissioner, and the Directorate of Higher Education. Blocks C and D house the Labour Commissioner’s offices. A police control room (dispatch center) is located in the basement of Block D.

The buildings were seismically assessed as part of the Delhi Earthquake Safety Initiative for Lifeline Buildings. This project was jointly funded by the Government of the National Capital Territory of Delhi and the United States Agency for International Development. GeoHazards International (GHI) formed a peer review panel of experts from India and the United States to guide Delhi PWD engineers through the seismic assessment and retrofit of five groups of important existing buildings, and to build their capacity to retrofit additional buildings in the future.

All four buildings at the Divisional Commissioner’s Office complex were found to be seismically vulnerable. Because the complex houses the primary officials responsible for disaster management, this vulnerability is a major concern. These officials will need to be able to manage the response following a damaging earthquake. Blocks A and B, which house these offices, are unreinforced masonry buildings that cannot provide high seismic performance with economically feasible retrofit solutions. For this reason, peer review panel members recommended to the Divisional Commissioner that they consider constructing a new emergency operations center that can be designed to remain operational after a large earthquake. Blocks A and B could be used for other purposes, or replaced. The Delhi government decided to retrofit Blocks C and D, but it is still considering whether to replace Blocks A and B or retrofit them.

Building Descriptions

The complex is located on Sham Nath Marg in North Delhi, near Ludlow Castle School. The Yamuna River flows about a kilometer east of the complex, as shown in Figure 1. The site has four main buildings in close proximity to one another, as the site plan in Figure 2 shows.
Figure 1. Location of office complex (yellow star) and other project buildings (red squares)
The following sections describe the four main buildings individually. Structural drawings were not available for any of the buildings, so Delhi PWD had measured drawings prepared by Vijay Engineering. Appendix A contains the complete sets of measured drawings for each building.

**Block A**

Block A was built in 1918 during the British period and is an example of colonial architecture. Because the building is ninety years old, it may qualify for heritage status. That designation would complicate both retrofit and replacement processes. Figure 3 shows partial elevation views of the building; the close proximity of other buildings makes it difficult to get a full elevation view. The building is a single storey unreinforced masonry structure with 480 mm (19 in) thick stone bearing walls and brick arches in the verandah. It is roughly H-shaped with many re-entrant corners, as the plan drawing in Figure 4 shows. The longitudinal section through the building in Figure 5 shows how the building’s walls vary in height and how the roof diaphragm is not continuous.

The roof over the verandah consists of brick jack arches. The original roof over the rooms was constructed of 300 by 150 mm (12 in by 6 in) clay tiles supported by 80 by 120 mm (3 by 5 in) wooden battens spaced at 300 mm (12 in) center to center, which in turn were supported on 310 mm (12 in) deep steel joists spaced at 2 m (6.5 ft) center to center. Some of the clay tile roofing has
been replaced with 600 by 600 by 40 mm (24 by 24 by 1.6 in) sandstone slabs supported by steel angles, which in turn are supported by steel joists. A brick wearing surface and waterproofing course covers the roof. The roof is not a contiguous structural unit and will not function as a diaphragm. Unfortunately, the brick arches, tiles, and stone slabs add a lot of mass, which will generate large seismic forces during an earthquake.

Figure 3. West elevation view (left; partial east elevation views with Block C in background (right)

Figure 4. Ground floor plan (dimensions in meters)
Delhi PWD determined that Block A was in good condition for its age, with no observed deterioration of masonry units or mortar. The windows have stone chhajjas (sunshades) that have weathered well.

**Block B**

Block B is a ground plus two storey brick masonry bearing wall building built in 1953, shown in Figure 6 below. The ground storey is significantly larger in plan than the upper stories, as Figures Figure 7 and Figure 8 show. The building has many window openings in the central portion of the front side, which reduce the strength of the walls. The building has reinforced concrete floor slabs throughout. The building appears to be in good condition.
Block C
Block C is a small office building completed in 1962. Fifty-five people from the Labour Department work in the building, it receives approximately fifty visitors per day. The building has a total floor area of 1313 sq m (14130 sq ft). Figure 9 and Figure 10 show the front and back elevations of the building in photographs and drawings, respectively. Figure 11 shows the ground floor plan. The building was not designed to resist earthquakes, because there were no seismic provisions in the building code in use at the time of its construction. Figure 9 shows the large concrete canopy over the entrance, which could fall and cut off access to the building.
The building has a hybrid structural system called the Bombay Pattern. The ground storey has load bearing stone and brick masonry walls, while the upper stories are primarily supported by a reinforced concrete frame. The two large end walls, as shown in the section in Figure 12, are bearing walls in all stories. These walls are 400mm (16 in) thick unreinforced stone masonry at the ground storey and triple wythe (345mm or 13.5 in thick) unreinforced brick masonry above. The front and back infill walls are double wythe (230 mm or 9 in thick) brick masonry.
Delhi PWD found that the building was in good to fair condition, with no deteriorated masonry units and with intact mortar. Sunshades, window projections, and the machine room roof showed some spalled concrete, and minor spalling was observed in some reinforced concrete columns. Equivalent cube strengths of two core samples from the column and slab were 17.25 MPa (2.5 ksi) for the slab and 15.10 MPa (2.2 ksi) for the column. The compressive strength of the bricks was 9.71 MPa (1.41 ksi). Delhi PWD did not test the stone masonry.

**Block D**

Block D, shown in Figure 13, has four stories plus a basement that houses the police control room. It was built in 1968 and has a total floor area of about 1500 sq m (16,000 sq ft). The building is a reinforced concrete frame structure with double wythe (230 mm or 9 in thick) unreinforced brick infill panels. It has isolated footings under the reinforced concrete columns. The basement floor slab acts as a stitching slab between the columns. There is a concrete retaining wall around the periphery of the basement up to about 600 mm (2 ft) below the plinth. An underground water tank is located adjacent to the basement. The building is regular in plan except for staircases in the southwest corner, as Figure 14 shows. These staircases limited the type of external retrofit scheme that could be used. The building also has a large concrete canopy over the entrance, shown in Figure 15. The building shows some deterioration but is in good to fair overall condition.
Figure 13. North (left) and south (right) elevation views

Figure 14. Ground floor plan (dimensions in meters)
Site Seismic Hazard

Ground Shaking
The ground shaking hazard for the purposes of engineering design was defined by the seismic zoning map and response spectrum given in Indian Standard 1893 (Part 1):2002 Criteria for Earthquake Resistant Design of Structures. For Delhi, the Maximum Considered Earthquake (MCE) peak ground acceleration (PGA) is 0.24 g. The project did not have the time, political backing, or funding to conduct site-specific hazard analyses. Some existing studies helped panel members to assess, in a very limited sense, whether the code values were appropriate for design. A study of seismic hazard by Iyengar (2000) indicates that acceleration between 0.18 and 0.23 g can be expected at rock level for an earthquake with a 2% probability of exceedance in 50 years (this corresponds to an earthquake with a return period of 2500 years). An older analysis by Khattri (1992) suggests that Delhi will see shaking on the order of 0.2g from an event with a 10% probability of exceedance in 50 years (this corresponds to an earthquake with a return period of 475 years). Shaking will be stronger at soil sites due to site amplification, and the Indian Meteorological Department is preparing a microzonation map that will quantify the amplification in various areas. The Global Seismic Hazard Assessment Project (GSHAP) map gives a PGA of about 0.14g for Delhi.

However, these probabilistic assessments were made without the benefit of extensive earth science studies to better define the hazards posed by local seismic sources and the likely size and recurrence interval for Himalayan events. GHI anticipates that current and future studies by earth scientists will lead to better quantification of Delhi’s seismic hazard and to revision of the design shaking values. Based on the currently available earth science information and studies discussed above, the peer review panel did not view the code values as unconservative.
Geotechnical Conditions
The site is flat and is not susceptible to landslides, and is not near any known faults. It is situated approximately one kilometer from the Yamuna in an area that is an abandoned channel of the river, as Figure 1 shows, so liquefaction is a possibility. Delhi PWD performed a geotechnical investigation in May 2005, when they drilled one 15 m (49 ft) borehole midway between the four blocks, as shown in Figure 2.

The soil is well graded silty sand and sandy silt with low plasticity. Figure 16 shows observed static penetration test (SPT) and dynamic cone penetration test (DCPT) values. The water table was observed at 6.80 m (22 ft) below the existing ground level during the dry season and at 5 m (16 ft) during the rainy season. The Dynamic Cone Penetration test was performed as per IS 4968, part 1, 1976 using a 50 mm diameter cone. No voids or organic matter were observed. Initial analyses by Delhi PWD showed that liquefaction was not likely to occur.

![Figure 16. SPT (left) and DCPT (right) values from the borehole; corrected values are shown in pink](image)

Design Criteria
The peer review panel recommended the use of a two-level performance criterion for all project buildings. Relations between the performance level, the design earthquakes in the IS 1893 code, and the peak ground acceleration are shown in the table below. Except for Immediate Occupancy, all the performance levels below permit significant structural damage that may or may not be economically repairable. The Life Safety plus Damage Control level keeps the occupants safe from structural failures during the earthquake and ensures that they can exit the building safely afterward. The peer panel attempted to relate the retrofit performance criteria back to the Life Safety performance intended by the IS 1893 code provisions, and decided that recommended criteria for enhanced performance are philosophically equivalent to designing the building to life safety for a larger ground motion.
Earthquake

The Consultants

Delhi

in analyses.

masonry

Any

because

I=1.5

items

of

provides

Building’s

The

ASCE

Structural

Performance Level | PGA (g) | Performance Level | PGA (g)
---|---|---|---
Hospitals | Immediate Occupancy* | 0.12 | Life Safety | 0.24
Non-hospitals | Life Safety + Damage Control* | 0.12 | Collapse Prevention | 0.24

*These performance criteria are considered to be philosophically equivalent to using i=2.0 for hospitals and i=1.5 for non-hospitals, which give Life Safety performance at 0.24g for hospitals and 0.18g for non-hospitals. Any actual designs using IS 1893 will use 0.24g for hospitals and 0.18g for non-hospitals.

<table>
<thead>
<tr>
<th>Buildings</th>
<th>PGA (g) for which above criteria correspond to Life Safety using IS 1893</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitals</td>
<td>0.24</td>
</tr>
<tr>
<td>Non-hospitals</td>
<td>0.18</td>
</tr>
</tbody>
</table>

The retrofit measures in IS 13935, which were proposed for Blocks A and B before Delhi government decided they might be replaced rather than retrofitted, were written to bring the building up to an earthquake resistance equivalent to that provided for new buildings in *Indian Standard 4326:1993 Earthquake Resistant Design and Construction of Buildings – Code of Practice*. The performance goals of IS 4236 are not explicitly stated, but it is assumed that the code is designed to provide life safety in the design earthquake (now the DBE based on the latest revision of IS 1893). It is unclear if the IS 13935 retrofits proposed for Blocks A and B could achieve performance higher than life safety, because IS 13935 does not include an explicit mechanism for tying its measures to performance.

**Structural Assessment and Analysis**

Delhi PWD assessed Blocks A and B using the IS 13935 provisions, as contained in the draft revision. Delhi PWD used the ASCE 31 Tier 1 Checklist to screen Blocks C and D for seismic deficiencies. Ahuja Consultants performed three dimensional linear analyses of the existing buildings, and then assessed the effectiveness of the shear wall retrofit schemes using linear finite element analyses. All of the buildings are relatively small and simple, so the peer review panel did not recommend any nonlinear analyses.

**ASCE 31 Tier 1 Checklist/IS 13935 Check**

The IS 13935 provisions provide a check of the building’s compliance with the prescriptive measures provided in IS 4326, the Indian Standard for the earthquake-resistant design of unreinforced masonry buildings. These measures include seismic bands, vertical corner reinforcement and limits on the size of openings. If the building does not comply with the IS 4326 provisions, then IS 13935 provides prescriptive actions that the authors determined to be equivalent.

**Block A**

The building does not have seismic bands or corner reinforcement and has many arches. All of these items are deficiencies identified by IS 13935. A full tabulation of the deficiencies was not available at the time of this report. During the site visit, peer review panel members also noted that the building has an archaic roof type, with tiles supported by steel beams. Because of this system and the discontinuities shown in Figure 5, it is unlikely that the roof provides any diaphragm action. During the design earthquake (DBE), the heavy roof will generate large seismic forces but will not distribute
them or restrain the walls. These forces are likely to cause severe cracking of the masonry walls and potentially, cause stones or bricks to fall from the roof. Under the MCE, portions of the building might collapse if not retrofitted or replaced.

**Block B**
The building does not have seismic bands or corner reinforcement and has many openings on the front side, including arches in the ground storey. All of these items are deficiencies identified by IS 13935. A full tabulation of the deficiencies was not available at the time of this report. However, the building is likely to be badly damaged in the DBE and might collapse in the MCE, if not retrofitted or replaced.

**Block C**
Delhi PWD used the ASCE 31 Tier 1 Checklist for concrete moment frames with masonry infill walls (US Federal Emergency Management Agency model building type C-3). The building is a hybrid type with some bearing walls, but Delhi PWD deemed that Type C-3 was the closest available type. Delhi PWD identified the following items as non-compliant (meaning that they were deficiencies):

- Weak storey
- Soft storey
- Discontinuous vertical elements
- Stress in unreinforced masonry walls

In addition, the reinforced concrete frames lacked ductile reinforcement detailing, because the building was built before such details were required.

**Block D**
Delhi PWD used the ASCE 31 Tier 1 Checklist for concrete moment frames with masonry infill walls (FEMA model building type C-3). The following items were identified as non-compliant (meaning that they were deficiencies):

- Interferring walls

The reinforced concrete frames also lacked ductile detailing.

**Elastic Analysis**
No elastic analyses were conducted for Blocks A and B.

**Block C**
The building’s hybrid structural system proved to be a challenge to model and analyze. Ahuja Consultants modeled the two main load bearing walls at the east and west ends as brick columns with brick infill panels. In the interior of the building, where the reinforced concrete frame was not continuous, the slab between the columns was modeled as a shallow beam. Brick columns were modeled with end releases, so that they wouldn’t participate in the lateral load system. Preliminary analysis showed that the foundation was inadequate, so Ahuja Consultants added soil stabilization with cement grout to the retrofit solution and included an assumed post-stabilization soil modulus of 3 kg/cu cm. Brick partitions were modeled with equivalent compression struts (cross-braces).
analysis showed that the columns in the ground storey would fail and would generate a soft storey mechanism in the longitudinal direction.

Ahuja Consultants proceeded to develop a retrofit scheme, as discussed in subsequent sections, and to analyze the proposed retrofit scheme using linear finite elements to model the shear walls. Figure 17 shows the model. The analysis demonstrated that the design would make the building perform as intended. Ahuja Consultants used an inventive method to make a linear analysis show what would happen if the columns and beams failed: the beams and columns were modeled with pinned-pinned end conditions. The results of this analysis showed that even if the beams and columns completely failed, the building would maintain its gravity load carrying capacity and would not collapse.

![Finite element model of shear wall retrofit scheme](Load 1)

**Figure 17.** Finite element model of shear wall retrofit scheme

**Block D**

Ahuja Consultants analyzed four different models of the building. Figure 18 shows Model 4.

1. Bare frame without shear wall.
2. Frame with brick bracing without shear walls.
3. Frame with brick bracing and shear walls.
4. Assume all braces crushed and columns hinged top and bottom.
Model 4 was included because analyses of the other, more realistic models showed that the beams and columns were overstressed enough potentially to fail. This was a linear analysis, so there was no way to determine the likely nonlinear behavior. Ahuja Consultants used the same strategy as in the case of Block C, and the analysis results showed that even if the beams and columns completely failed, the building would maintain its gravity load carrying capacity and would not collapse.

Retrofit Scheme Selection

Recommended Retrofit Scheme

Engineering drawings for the seismic retrofit of Blocks C and D are located in Appendix B.

Blocks A and B

If Block A and B are to be retrofitted, they will be retrofitted using the IS 13935 approach, with some modifications to address architectural and historic preservation concerns or conditions that fall outside the scope of IS 13935.

Block C

Block C is being retrofitted using a scheme that consists of:

- C-shaped external shear walls that form “bookends” on each end of the building;
- A grade beam below the ground floor level to spread out the overturning forces from the shear walls;
- External tie beams that connect the two bookends at the roof; and
- L-shaped extensions to the original foundations and soil grouting to stabilize the subsoil.

The design engineer, Mr. Vipul Ahuja, wrote the following explanation of how his firm selected the scheme:
The brick wall system is very sensitive to drift and any retrofitting measure must be so stiff that the shear deformation in brickwork is restricted (3 to 4 mm). The infilled wall panels are modeled as two transverse diagonal struts joining the two columns. The infilled panels are weak in compression but also have a damaging effect on the columns between which these infill walls are located. Any steel frame retrofitting measure would have resulted in very much larger strains. Hence the choice was made to work with in-situ concrete shear wall system, which could provide a reasonable stiff structure.

A “book-end” type shear wall system was considered most appropriate. One solution required the digging of the foundation right all the way to the base of the existing footing. There would have been danger of the existing ground floor being undermined. Therefore it was decided to limit the depth of excavation. However the soil was not firm above the level of foundation since it is usually filled back earth. Therefore it was decided to stabilize this filled up part. Logically the wall had to have a spread out bottom so as to take advantage of this grouted earth. Thus an “L” shape emerged of the footing for the shear walls. Further to limit the pressures the book ends were tied together with a band, both at the foundation level (below ground floor) and at the roof level—so as to give a sort of a Verendeel truss action. The roof level band emerged in the form of the parapet that was required anyway from architectural/ functional consideration. The horizontal band at the ground provided sufficient bearing on soil to pick up a larger proportion of the earthquake resisting moment as compared to that of the interior columns and the older foundations.

The special difficulty experienced in the design was excessive bearing pressures on the ground under the peripheral columns and strip footings with the vertical RCC band. However with the L-shaped RCC band, the value was restricted to about 10t/m^2 under the horizontal part of the L and marginal increase under the older foundations in the periphery. This will ensure that the reasonable small pressure under earthquake is adequately taken care of. However not withstanding this low pressure it is stipulated that the periphery of the building especially under the L-shaped band and the columns and wall footings on the periphery be grouted with cement slurry under high pressure. This will help guarantee achieving a reasonable value of at least 10 t/sqm. Normally in this neighbourhood, the buildings are designed for 10 to 12 t/sqm.

**Block D**

Block C is being retrofitted using a scheme that consists of:

- L-shaped external shear walls that form “bookends” on opposite corners of the building;
- A large ring beam the depth of the basement to spread out the overturning forces from the shear walls;
- Vertically oriented fiber wrap strips to prevent out-of-plane failure of brick infill walls; and
- Extensions to the original foundations under the new shear walls.

The design engineer, Mr. Vipul Ahuja, wrote the following explanation of how his firm selected the scheme:

*The maximum permissible strain in brickwork had to be limited so as to avoid shearing of the columns and crushing of the infill brick panels along the diagonals. The geometry of the building did not permit any shear walls on the two opposite corners due to presence of staircases. The other two diagonals were otherwise available except for the presence of the adjacent underground water tank,*
which butted against the basement of the building. Due to limited length of shear wall available on two opposite corners a horizontal band butting against RCC basement wall was considered together with a parapet in RCC at the top. The foundation pressures at certain places have increased by 30% due to EQ. For this reason no further treatment to the foundation is stipulated because it is considered firstly the bearing pressure under the first instance were not too high & secondly because the code allows 25% increase on account of the earthquake.

Anticipated Performance After Retrofit
Blocks C and D are expected to perform at a level above life safety. Both shear wall retrofits were conservatively designed, so the performance may be significantly higher. The design was based on a linear analysis, and was not checked for performance acceptability using FEMA 356 nonlinear analysis methods.

Alternative Schemes Investigated

Blocks A and B
Delhi PWD did not investigate retrofit schemes other than IS 13935-prescribed seismic belts. The American peer review panel members expressed concerns about how the IS 13935 system would be applied to a historic building and whether the provisions adequately addressed the archaic roof system. The Delhi government began to seriously consider replacement before these concerns could be fully addressed, however.

Block C
Ahuja Consultants considered a steel braced frame alternative, in addition to the selected shear wall scheme. The steel scheme proved unworkable because a large amount of steel was needed to provide sufficient stiffness. In addition, the peer review panel preferred concrete solutions because they were more compatible with local construction practices and therefore, more economical and likely to be replicated in other buildings.

Block D
Ahuja Consultants did not investigate alternate schemes for Block D.

Functionality, Architectural, and Disruption Considerations
As a potential heritage building, Block A presents architectural and historic preservation issues, which Delhi PWD will need to address if the Delhi government decides to retrofit the building. The other buildings do not have any architectural constraints on the retrofit scheme. Block D could not be retrofitted with internal shear walls or other invasive schemes, due to the need to keep the building operational during retrofit. The police control room remained in operation, as shown in Figure 19 below.

Engineering Design and Construction Documents
Ahuja Consultants Pvt. Ltd. designed the seismic retrofits for Blocks C and D. Appendix B contains the construction drawings. Delhi PWD had not finalized the retrofit designs for Blocks A and B when the
Delhi government began to seriously consider replacing them. At that point, Delhi PWD stopped work on the design and did not complete engineering drawings for either building.

**Cost Estimates**
The total retrofit cost for Block D was 49 lakh rupees, approximately 25% of the estimated replacement cost. At the time of this report, Block C’s retrofit design was awaiting sanction by the Labour Department. The total estimated cost for Block C is 65 lakh rupees. Of this amount, the structural retrofit costs 61 lakh rupees and architectural finishes make up the remainder. The total retrofit cost is approximately 38% of the estimated replacement cost, and the structural retrofit cost is about 36% of the estimated replacement cost.

**Construction and Quality Control**
Construction began at Block D in November, 2007. Construction work was not complete at the time this report was written in December, 2008. A number of factors contributed to the delay. Disruption management was hampered by a lack of pre-construction communication between building occupants and the contractor, leading to unplanned delays during construction. The contractor and PWD engineer in charge both had deaths in their families, further delaying the work. The contractor was not particularly efficient and could not manage the complicated site constraints, occupant complaints, and other matters in a way that kept the project on schedule. Delhi PWD provided construction quality control in accordance with their standard procedures and protocol. Figure 19 shows construction underway.

![Figure 19. Peer panel members at site (left); access to police control room maintained during construction (right)](image)

**Mitigation of Falling Hazards**
The complex has a number of falling hazards, including air coolers, parapets, stone window shades, entrance canopies, and rooftop water tanks. In addition, important records are stored in open, unbraced shelves in Block A. Delhi PWD plans to address these issues, after the structural retrofits are complete and Delhi government has reached a decision on Blocks A and B.
Conclusions
The Divisional Commissioner’s Office Complex consists of four buildings that house the Divisional Commissioner, DDMA, the Labour Commissioner, and a police control room. Because of their age and construction type, all of the buildings were found to be vulnerable to earthquake damage that would threaten the lives of their occupants. The Delhi government decided to seismically retrofit the reinforced concrete buildings, Blocks C and D, using external shear walls shaped like bookends.

At the time of this report, construction was well underway at Block D, the Block C design was up for sanction, and the Delhi government had not yet made a final decision on how best to manage the substantial earthquake risk posed by Blocks A and B. The government is likely to replace these older unreinforced masonry buildings rather than retrofit them. Block A is ninety old and may be eligible for heritage status, which would complicate the risk management process, no matter the decision. The building has some compelling architectural features that may justify preservation. Regardless of the outcome, the process illustrates some of the important issues that owners face when trying to identify and reduce the earthquake risks posed by masonry buildings. The buildings at 5 Sham Nath Marg are good examples of the older small office buildings that house many government offices throughout the country. Project participants encourage the assessment and retrofit of other buildings like these in areas of high earthquake hazard, and hope that this project provides instructive examples of how that can be accomplished.
Appendix A: Measured Drawings

Block A

LAYOUT PLAN OF BLOCK 'A'

LONGITUDINAL SECTION AT A- A
Block C
Block D

Basement Plan
BLOCK 'D'
First Floor Plan
BLOCK D
LONGITUDINAL SECTION AT A’A
BLOCK ‘D’
Cross Section at X'X
Block 'D'
Appendix B: Seismic Retrofit Construction Documents

Block C
Block D